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IMPACTS OF CLIMATE INDUCED WATER SCARCITY ON HYDROPOWER SECTOR – CASE STUDY OF HPPs CRN DRIN, NORTH MACEDONIA

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Abstract:
Water scarcity escalating by long and frequent droughts is becoming a raising trend in many regions globally. Environmental, social and economy sectors have been jeopardized thereby, in their survival, operation and development.

Water resources sustainable planning and management in long term has to respond to new challenges, due to more intensive and uncertain climate change impacts, demographic trends and economy growth, resulting in more intensive water resources demand.

The water deficit jeopardizes the long term operation and production of energy, as one of the main pillars of development of society and economy.

The paper presents implementation of an integrated simulation hydro – climate - energy model in the course of the project ARSINOE (https://arsinoe-project.eu/), in the Case Study of Ohrid and Prespa Lakes, shared by three countries (North Macedonia, Albania and Greece), to provide an improved representation of integrated transboundary water management under climate change scenarios, with a specific focus on energy sector (hydro power generation), its exposure and climate adaptiveness.

Keywords: *Water scarcity; Energy sector, Climate resilience and adaptiveness.*

1. Introduction

Increasing energy and water resources demand and intensified impacts of climate change pose growing challenges to energy generation and transmission systems. Economy development and raising of population number increase demand for energy and change the patterns of the electricity delivery and distribution in the grid. At the same time, despite new generation capacity additions to the grid, the power output of the generating assets is projected to significantly decrease as a direct impact of climate change.

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Energy sector is one of the mostly affected by climate changes, particularly the generation plants that use water resources: hydro power plants (HPPs), thermal power plants (TPP), nuclear plants...

The water deficit has a negative impact on the long - term operation of such plants and production of energy, which is one of the main pillars of development of society and economy.

In some cases, when water resources are shared among multiple users, the energy sector has to be involved in consensual decisions of fair water allocation and use, which may include trade - offs, with sectors that are usually prioritized, such as environmental ecosystems, society (household's water supply), etc.

There is a need to develop and deploy comprehensive, multidisciplinary and complex analytical approaches that can show a correct identification and setting of water issues, enabling decision making under deep uncertainty of water availability and including all affected sectors in finding solutions. This is particularly of importance in case of water deficit and scarcity, under conditions of transboundary share of the same water resources

The overall objective of the modelling and simulation in the field of climateb changes and energy sector is to more effectively articulate the issue of climate change - induced water scarcity on power production and put it on the policy and developement agenda that provides an initial, quantitative view of the water intensity of the energy sector and the resulting water scarcity risks that owners / operators of power production facilities can face.

IWaMM is an integrated water management model across environmental, social and economy sectors, developed and demonstrated as a research project (TRL7) by IECE, North Macedonia. It calculates and presents results of simulations of a complex hydro system operation under superposed climate and socio – economic scenarios. Simulation includes Business As Usual, as well as adaptiveness strategies, applied in form of suggested measures / actions for rational and effective use of water across sectors, thus ensuring water availability within the analyzed time frame.

The core loop is the mass balance as the governing equitation set for a hydro system that includes a reservoir (natural - a lake or artificial – dam impounded), supply and demand side, as well as losses, optimizing water preservation in terms of providing a long term availability and preventing overflows as well as water deficit. Calculations include water stocks and flows across sectors, in discrete time steps (mean monthly water volumes), identifying deficits (and time spots of occurrence) that may appear as a result of climate influence or / and sector policy.

Time resolution on a monthly basis (mean monthly values of observed and projected data) is applied, in order to capture seasonal character of some of the users (e.g. agricultures, tourism), which usually coincides with the seasonal minimum of water natural supply or recharge.

In the course of the project ARSINOE, the model was deployed in the Case Study of Ohrid and Prespa Lakes that are shared by three countries in the Western Balkan region: North Macedonia, Albania and Greece (presented in the Figure 1 below). Model demonstration was carried out, in order to provide an improved representation of a climate resilient, cross sectoral and transboundary integrated water management under climate change scenarios. Applying this integrated approach enabled a correct identification and setting of water issues, as well as informed decision making, under deep uncertainty of climate pressures. One of the main modelling outputs was estimation of impacts of forecasted water scarcity on electricity production in the HPPs located in the region.

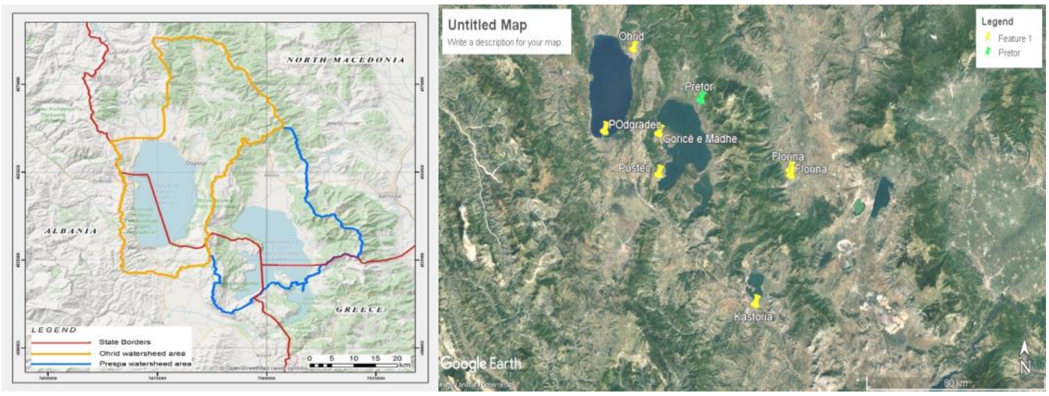

Figure 1.

Ohrid (1.404 km2) and Prespa watershed (1.360 km2) boundaries and location of meteorological stations

(Source: Google maps)

2. MATERIALS AND METHODS

2.1 Description of the HPPs Crn Drin

The system of hydro power plants on the river Crn Drim consists of cascade of dams, reservoirs and hydro power plants, two in North Macedonia (HPP Globochica and HPP Shpilje) and three in Albania (Fierza, Koman and Vau e Dejes) The system starts in North Macedonia, from the Ohrid Lake, wherefrom the river Crn Drim outflows, at the town of Struga.

Ohrid Lake is a natural reservoir and the largest lake in the country, with annual water balance levelling and regulated discharge of the Crn Drim River. It forms a natural hydraulic phenomena with the Prespa Lake, receiving waters therefrom thorough the groundwater discharge below the mountain of Galichica. The lake area is 350 km^2 with a maximum depth 290 m. In compliance with the agreement between North Macedonia and Albania, in order to preserve the valuable biological ecosystems, the lake water level is maintained in the span of 693, 10 masl to 693,75 masl, exceptionally up to 694.00 мнм. This allows oscillations of the lake water level in the span of 0.65 m (maximum of 0.90 m). It also provides for flooding protection of the coastal area and settlements at both sides. The mean water level of the lake in the period 1980-2020 was 693.45 masl.

Figure 2 below presents the scheme of the HPPs on the Crn Drin River, in North Macedonia (HPPs Globochica and Shpilje).

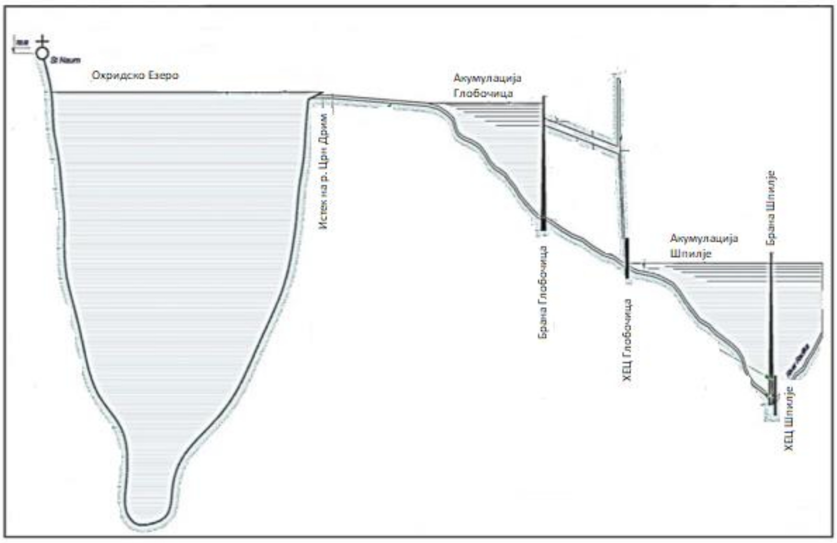

Figure 2. *Hydro power plants on the Crn Drim River in North Macedonia*

Hydropower plants Fierza and Komane are storage plants with a seasonal water balance levelling, being in continuous operation since 1974 and 1988, respectively. Hydropower plant Vaue E Dejes is a run of the river plant, in operation since 1973. Layout of the cascade is shown in the Figure 3 below.

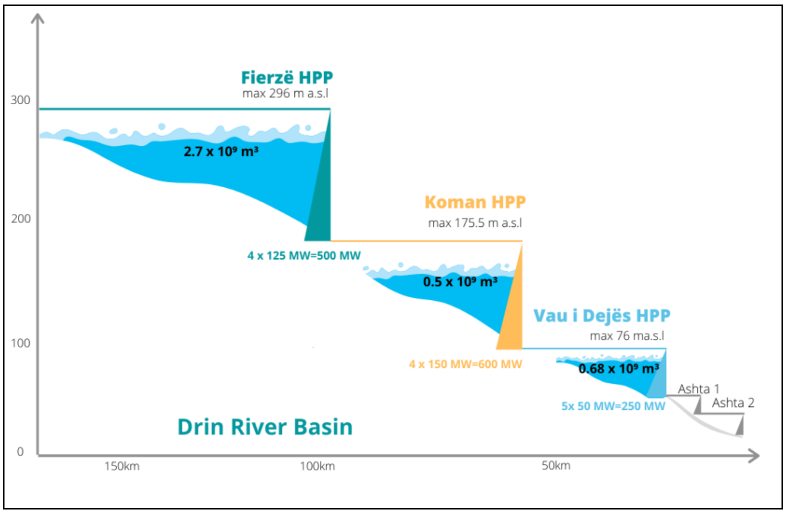

Figure 3. *Hydro power plants on the Crn Drim River in Albania*

The Table 1 below presents the basic characteristics of the HPPs Globochica, Shpilje and Fierza.

Table 1: *Overview of the basic features of HPPs Globochica, Shpilje and Fierza*

X	***HPP Globochica***	***XHPP Shpilje***	***HPP Fierza***
Type of plant	*Storage, derivation*	*Storage, near to dam*	*Storage, near to dam*
Location	25 km north from Struga	Town of Debar	North Albania
Watershed	Crn Drim River	Crn Drim River	Crn Drim River
Number of generating units	2	3	4x125
Installed power	42 MW	84 MW	500 MW
Average annual power generation	180 GWh	272 GWh	1330 GWh
Commissioning	1965	1969	1980
Net head	97,5 м	85,2 м	118 м
Installed flow	50 (2×25) m^3/s	108 (3×36) $м^3/s$	116 $м^3/s$
Specific water consumption	4.25 m^3/kWh	4.5 m^3/kWh	4.39 m^3/kWh
Turbine type	Francis	Francis	Francis

2.2 Description of the method

The method of the simulation and optimization model IWaMM is specific in its composition, complementarity and integration of the analytical, planning and simulation part.

- Analytical: Data collection, sectors identification, diagnosis of water scarcity, baseline setting
- Simulation: Climate – hydro climate modelling enables creation of projections that help understand / forecast availability of water in the region and the observed sectors;
- Planning: Identification of endangered sectors, selection of priorities, fair allocation and operation regime, ranking and scheduling of adaption strategies, for a long term management of water resources in a climate resilient manner

Hydro - climate modelling is based on a seven - step methodology:

- Step 1: Setting of the baseline – Analytical part
- Step 2: Development of hydro – climate projections up to the projecting horizon - Simulation part
- Step 3: Water balance projections of the two lakes,
- Step 4: Socio – economic projections (GDP, population growth) that impact water consumption,
- Step 5: Water consumption projection per social and economy sectors
- Step 6: Energy production projections
- Step 7: Identification, ranking and selection of adaptiveness strategies of water use across sectors – Planning part

2.3 Selection of modeling parameters for hydro climate projections

The following parameters for the modelling procedure were adopted:

- Climate scenarios: RCP 2.6 and RCP 8.5, with data downscaled from RCMs, CMIP5 series,
- Socio – economic scenarios coupled with selected climate change scenarios: SSP1, SSP5,
- Representative climate change indicators: mean monthly sum of precipitations and mean monthly air temperature,
- Time projection horizon: 2100; milestone: 2050,
- Time resolution: mean monthly data,

- Spatial coverage: watershed areas of Ohrid and Prespa Lake (about 1400 km^2 each).

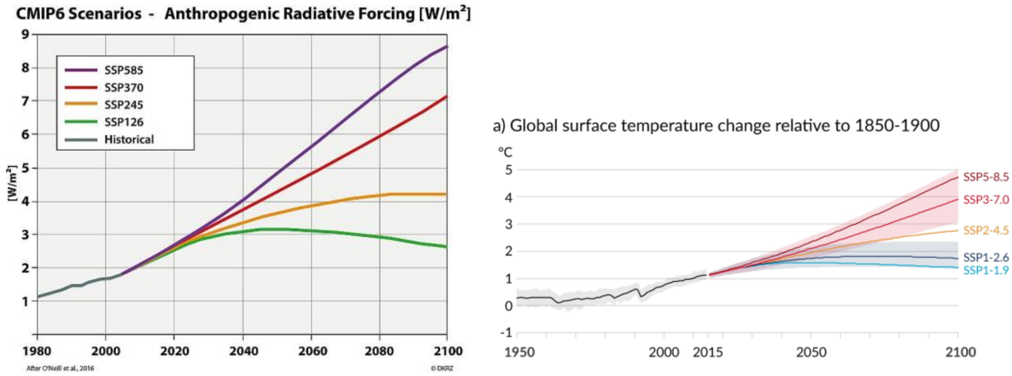

Figure 4. *RCP Scenarios and corresponding projected global warming*

2.4 Water balance modelling

By applying hydro – climate model outputs in the water balance equation, projections of the water level fluctuations on monthly basis, by 2100, were estimated, for each of the lakes, under the two selected climate scenarios: RCP 2.6 and RCP8.5.

The projected values of mean monthly sums of precipitation and mean monthly air temperature are included in the lake water balance equation (1).

$$St+(P+Qin+Gin) - (E+ET+Qout+Qws+Qir+Gout)=St+\Delta t \quad (1)$$

- ST - Initial water storage in the watershed at the beginning of the analyzed period
- P – Input water in the watershed due to precipitation = f (mean sum of precipitations)
- QIN – Input water in the watershed from another watershed Gin – Groundwater inflow
- E – Output water due to evaporation from free surface water = f(mean air temperature)
- ET – Output water due to evapotranspiration = f(mean air temperature)
- QOUT – Outflow water to another watershed
- QWS – Used water for population and industry and water supply
- QIR – Used water for irrigation
- GOUT – Groundwater outflow
- St+Δt - Water storage in the watershed at the end of the analyzed period

Mathematical relation of the Ohrid Lake water balance in a condensed form is:

$$St + (P+Gin) - (E+ET+ Qws+Qir) = Qout * T \qquad (2)$$

Ohrid Lake water regulated discharge into the Crn Drin River, for RCP 2.6 and RCP 8.5 is included as an input in the energy module, to calculate annual electricity production.

This was further improved and aligned to real operational regime of the first HPP in the cascade, based on measured (observed) data in the past 40 years (1980 -2020).

2.5 Energy generation projections

For calculation of the available water volumes in the conditions of climate changes, projections were made of the Crn Drin outflow from the Ohrid Lake, in the period 2021-2100, on the basis of the measured data from the meteorological and hydrological measuring stations in the watershed, provided for the period 1981-2020.

The Ohrid Lake water level in the projecting period of .2021 to 2100, was taken as a constant value of 693.50 masl.

Calculation of the discharge was made for two scenarios, RCP2.6 and RCP8.5

Simulation of the energy module was made in order to estimate the impact of change of the outflow of the Crn Drin River, in compliance with the observed climate scenarios, on the power generation in the HPPs in the cascade, in the period 2021-2100.

Analysis was carried out on the impact of climate changes on the power generation in HPPs Globochica, Shpilje and Fierza, as well as impact assessment for the HPPs Koman and Vau I Dejës.

Figures 5 and 6 (below) present distribution of the available discharge volume by months, at constant water level of the Ohrid Lake, for two climate scenarios.

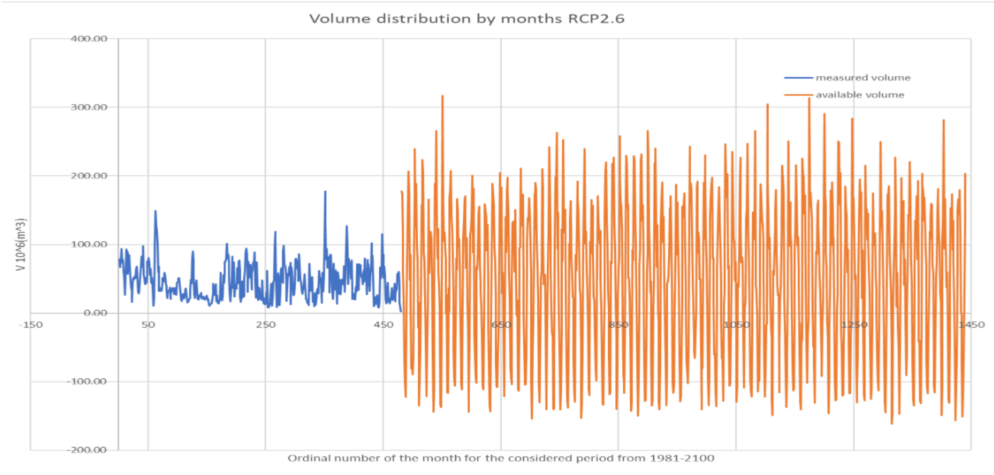

Figure 5. *Distribution of the available discharge volume from the Ohrid Lake [m³], by months, at constant water level of 693.5 masl, climate scenario RCP 2.6*

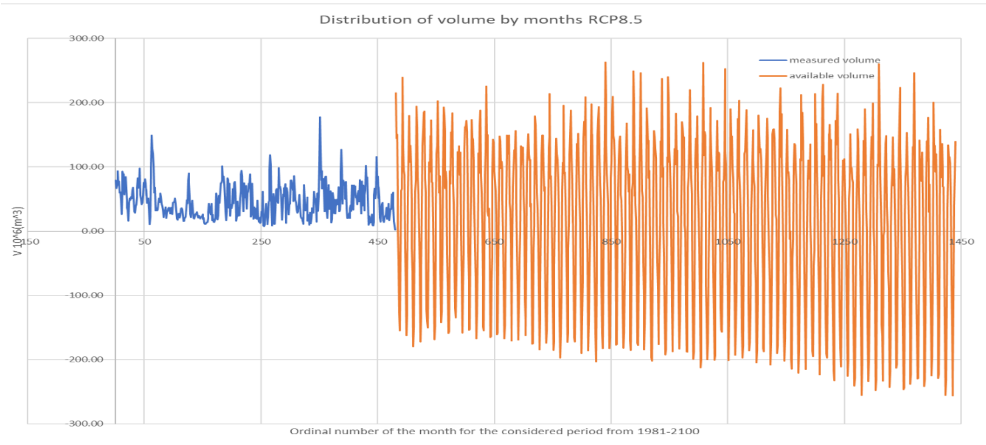

Figure 6. *Distribution of the available discharge volume from the Ohrid Lake [m³], by months, at constant water level of 693.5 masl, climate scenario RCP 8.5*

Figures 7 and 8 (below) present mean annual discharge [m3/s], from the Ohrid Lake, in period 1980-2100, for two climate scenarios.

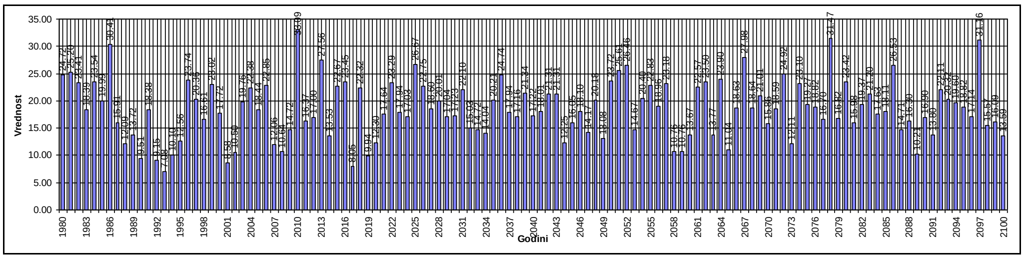

Figure 7. *Mean annual discharge [m³/s], from the Ohrid Lake, in the period 1980-2100, climate scenario RCP 2.6*

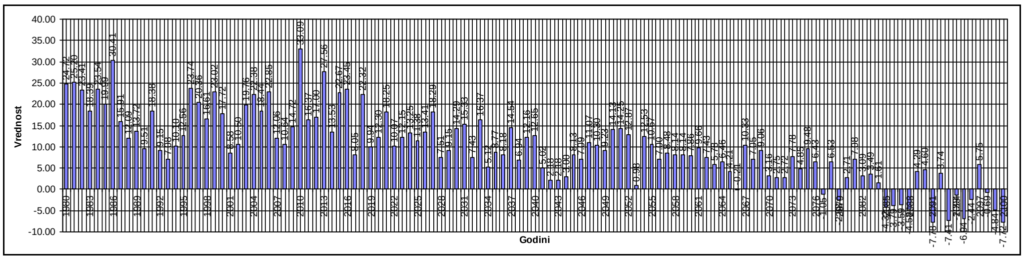

Figure 8. *Mean annual discharge [m³/s], from the Ohrid Lake, in period 1980-2100, climate scenario RCP 8.5*

Figures 9 to 12 (below) present forecasted contribution of the Ohrid Lake discharge in the total annual power generation [GWh], in HPP Globochica, and HPP Shpilje, in the period 2021 – 2100.

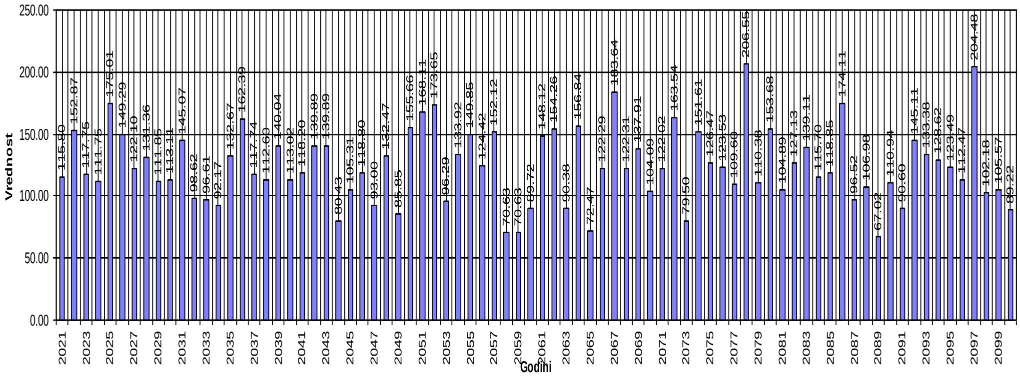

Figure 9. *Forecasted contribution of the Ohrid Lake discharge in the total annual power generation [GWh], in HPP Globochica, in the period 2021 – 2100, climate scenario RCP 2.6*

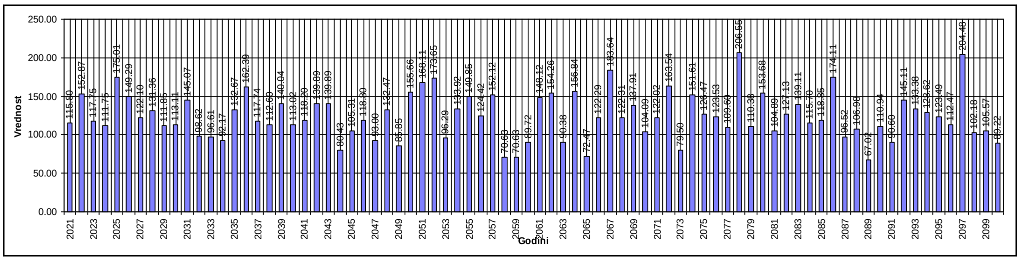

Figure 10. *Forecasted contribution of the Ohrid Lake discharge in the total annual power generation [GWh], in HPP Shpilje, in the period 2021 – 2100, climate scenario RCP 2.6*

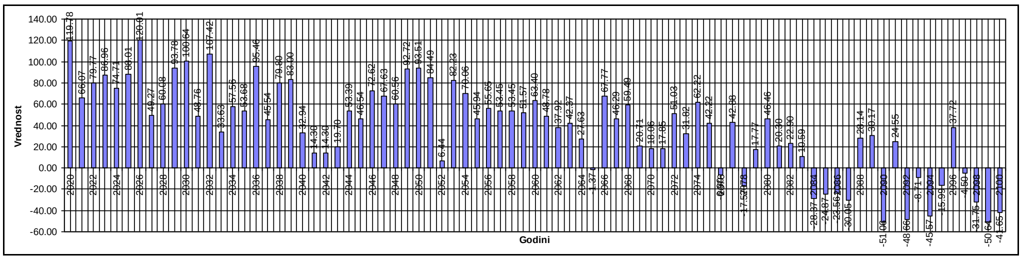

Figure 11. *Forecasted contribution of the Ohrid Lake discharge in the total annual power generation [GWh], in HPP Globochica, in the period 2021 – 2100, climate scenario RCP 8.5*

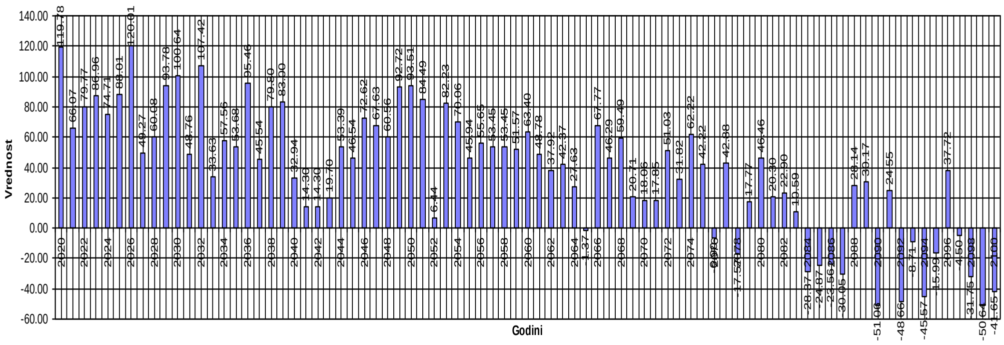

Figure 12. *Forecasted contribution of the Ohrid Lake discharge in the total annual power generation [GWh], in HPP Shpilje, in the period 2021 – 2100, climate scenario RCP 8.5*

3. RESULTS AND DISCUSSION

3.1 Analysis of results

The energy module was used to calculate the impacts of climate change on lowering of the regulated discharge from the lake Ohrid, and therefrom, on power generation in the cascade of five HPPs (two in North Macedonia and three in Albania). The figures 13 to 16 below present forecasted contribution of the Ohrid Lake discharge in the total annual power generation [GWh], in HPPs Globochica and Shpilje, in the total period 1980 – 2100, at two climate scenario (RCP 2.6 and RCP 8.5).

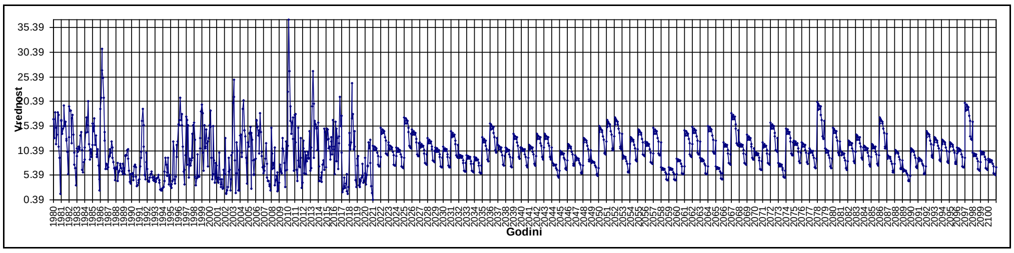

Figure 13. *Forecasted contribution of the Ohrid Lake discharge in the total annual power generation [GWh], in HPP Globochica in the period 1980 – 2100, climate scenario RCP 2.6*

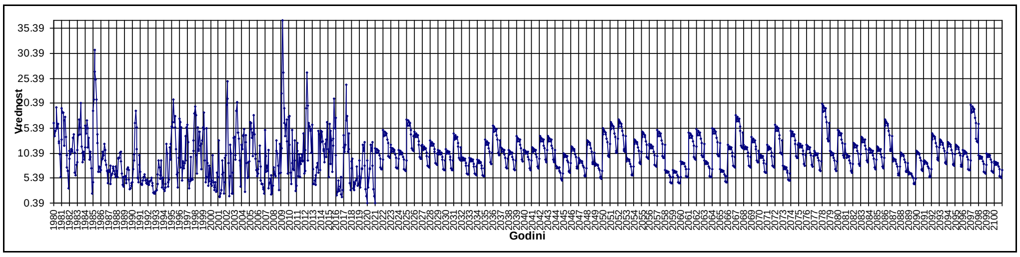

Figure 14. *Forecasted contribution of the Ohrid Lake discharge in the total annual power generation [GWh], in HPP Shpilje, in the period 1980 – 2100, climate scenario RCP 2.6*

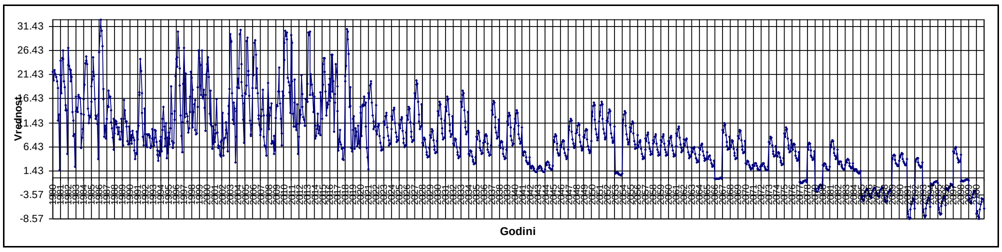

Figure 15. *Forecasted contribution of the Ohrid Lake discharge in the total annual power generation [GWh], in HPP Shpilje, in the period 1980 – 2100, climate scenario RCP 2.6*

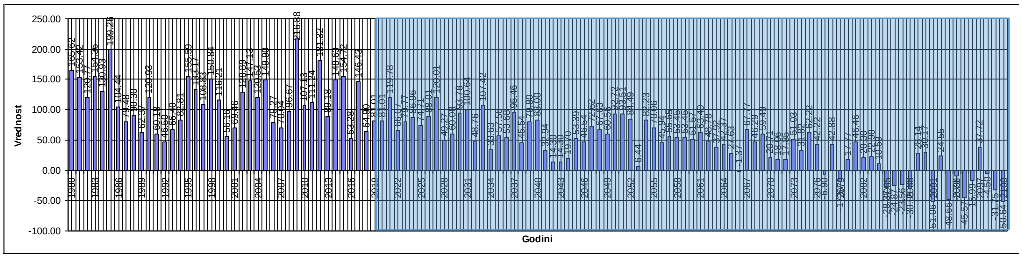

Figure 16. *Forecasted contribution of the Ohrid Lake discharge in the total annual power generation [GWh], in HPP Shpilje, in the period 1980 – 2100, climate scenario RCP 2.6*

The same analysis was replicated on HPP Fierza (Albania). An assessment of the impact of the reduced outflow was made for the remaining two HPPs in the cascade (Fierza and Vau I Dejes).

The main finding is that, in order to meet the environmental requirement, by maintaining the Current span of water level fluctuations in the Ohrid Lake, the regulated discharge would need to be adjusted to the availability of water. In the climate scenario RCP 2.6, differences are quite small in relation to the reference period (1980 - 2020), but the hydro power generation would decrease under RCP8.5, as a consequence of reduced discharge from the Lake.

The results showed that under RCP 8.5, the contribution of Ohrid Lake discharge will affect the power generation in HPPs Globocica and Shpilje, by approximately 50% of decrease, whilst the impact on the other three HPPs, downstream, will be below 10% (Tables 2 and 3).

Table 2: *Participation of outflow from Ohrid Lake in [GWh] of annual power generation in HPPs*

Time period, Climate scenario	*Participation of Ohrid Lake waters in power generation [GWh/annual]*		
	HPP Globocica (MK)	**HPP Shpilje (MK)**	**HPP Fierza (AL)**
1980 - 2020	113.62	120.68	125.10
2021 – 2100, RCP 2.6	121.14	124.33	160.29
2021 – 2100, RCP 8.5	38.31	64.47	102.29

Table 3: *Participation of outflow from Ohrid Lake in [%] of annual power generation in HPPs*

Time period, Climate scenario	*Participation of Ohrid Lake waters in power generation [% /annual]*		
	HPP Globocica (MK)	**HPP Shpilje (MK)**	**HPP Fierza (AL)**
1980 - 2020	67.06	39,34	5,25
2021 – 2100, RCP 2.6	69.74	40,30	6,73
2021 – 2100, RCP 8.5	21.91	21.02	2.29

3.2 Defining adaptation strategies

Apart from the economy – society – environment sector adaptivity, additional adaptation options were suggested and discussed with the relevant involved parties (energy system operators and users), for compensation of losses in hydropower generation. The adaptation strategies would include:

1) installation of floating photovoltaics in HPP reservoirs,
2) adaptation of hydro generating units to enable processing of low flows,
3) hydrogen generation in combination with renewable energy sources surplus generation.

4. CONCLUSIONS

Subject of energy generation simulations were forecasts of the change of the regulated discharge from the Ohrid Lake, as a consequence of climate changes, and estimation of the impact thereof on the power generation in the HPPs on the Crn Drin River.

In the climate scenario RCP 2.6, from 2021 to 2100 there will be cycles with an increased and decreased water availability, and the average value will be above those in the reference period (1980 to 2020). That is explained by domination of the precipitation impact which will have a cyclic character, at a continuous increase (yet, with a low gradient), of the air temperature (the second relevant climate factor), Therefore, the expected hydropower generation is slightly above the values in the reference period.

According to the climate scenario RCP 8.5, until 2100 there will be significant decrease of the regulated outflow into the Crn Drim River, which is explained by superposition of unfavorable trends of the two adopted climate change indicators, more precisely, the continuous negative trend of decrease of precipitations (seasonally and yearly) and positive trend of air temperature intensive increase.

The climate change would cause decrease of the regulated discharge from the Ohrid Lake, in RCP 8.5, and therefrom trigger a decrease of the power generation in HPPs Globochica and Shpilje, while less manifested at HPPs Fierza, Koman and Vau e Dejes.

For a complete assessment of the climate change impacts. In the phase of running simulations by the model implementation, other hydrological and, meteorological parameters in the watershed will be taken in consideration, as well as a model run for a climate scenario that is considered the most probable at the moment, RCP 4.5

That would enable a comprehensive insight in the expected impacts of the climate changes on the hydro power sector in the region, which would give a solid basis for an on – time and long term planning of adaptation strategies, aligned and harmonized with other economy sectors in a common sustainable development.

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